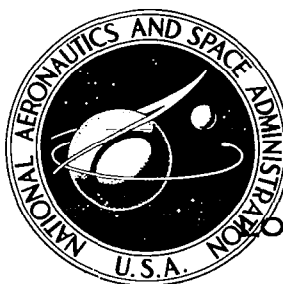




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SIMULATED INDOOR SONIC BOOMS JUDGED RELATIVE TO NOISE FROM SUBSONIC AIRCRAFT

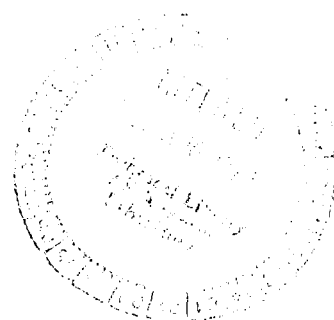
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CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	iv
LIST OF TABLES	v
INTRODUCTION	1
PROCEDURE	2
RESULTS AND DISCUSSION	5
CONCLUSIONS	11
REFERENCES	13
Appendix A--INSTRUCTIONS TO LISTENERS	A-1

LIST OF ILLUSTRATIONS

	<u>Page</u>
Figure 1 Showing Percent of People Who Preferred the Sonic Booms Indicated to Aircraft Noise Presented at Different Levels of Intensity	7
Figure 2 Correction to EPNL for Contribution to Perceived Noisiness of Startle to Expected Impulsive Sounds	10

LIST OF TABLES

	<u>Page</u>
Table I Test Sequences of Variations in Simulated Sonic Boom Signature and Rise Time Com- parison Noise With That From a Subsonic Jet, Landing at 5000 lbs Thrust	4
Table II Selected Parameters of the Stimuli Used	5
Table III Effective and Maximum Perceived Noise Levels of Aircraft Noise (Left-Hand Column) When Judged Equal to the Sonic Booms as Measured in Similar Units	8

SIMULATED INDOOR SONIC BOOMS
JUDGED RELATIVE TO NOISE FROM SUBSONIC AIRCRAFT

By Karl D. Kryter and Jerome S. Lukas

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INTRODUCTION

It is reasonably well established that weighting the spectra of outdoor sonic booms, or so-called N-waves, in accordance with equal loudness or equal noisiness contours provides a good means for predicting the judged relative loudness or noisiness of the booms. It would seem likely that the spectra of sonic booms, as found inside a house, should be treated in a similar fashion in order to predict their subjective noisiness. However, this possibility has not been tested to date because: (1) the spectra inside test houses exposed to sonic booms (ref. 1) varied so much from one listener's position to another a correlation analysis between the physical and psychological data was not feasible; and (2) in laboratory tests with simulated or recorded "indoor" sonic booms, the acoustical signals were presented via earphones or loudspeakers that could not transduce some of the audible intense low-frequency components of the boom (ref. 2,3).

However, the sonic boom simulator at Stanford Research Institute provides sound and vibrational signals to persons in a "living room" associated with the simulator that are valid representations of the acoustical environment to be found in a house exposed to an actual sonic boom (ref. 4). The peak overpressure, duration, and rise time, and therefore the spectra, of the simulated sonic boom imposed on the laboratory test room can, within limits, be systematically varied. In addition, recordings of the noise from subsonic aircraft or other audio signals can be presented to listeners via a loudspeaker system present in the test room.

Accordingly, a brief series of tests were conducted to investigate the following:

1. What is the effect of varying the rise time of sonic booms upon the perceived noisiness of the booms heard indoors, and judged relative to a standard reference noise from a subsonic jet aircraft? and
2. Can the results of the tests be predicted from the PNdB and dBA values measured in the test room during the

occurrences of the booms and the subsonic aircraft flyover noise?

It should be noted that the booms from supersonic aircraft and the flyover noise from subsonic aircraft are usually measured outdoors but that many people affected by these sounds are indoors. Because of spectral differences between these two types of sounds, their levels can be differentially affected by the sound attenuation afforded by a house. Accordingly, the levels of the boom and noise as they would be when measured both outdoors and inside a typical house will be herein reported.

PROCEDURE

Subjects. Twenty subjects ranging in age from 25 to 49 years (average age of 34.8 years) participated in this experiment. The subjects, from a much larger group used in another study (ref. 5) were selected to be of "average" sensitivity to noise as it was defined in that study. The subjects were rated as average on a noise sensitivity scale and, in general, thought themselves not to be adversely affected physiologically or psychologically by environmental noise. At all frequencies the audiograms for all subjects were within 15 dB of the hearing acuity of normal, young adults.

Experimental Design. The subjects, randomly divided into six groups, were each tested for three or four consecutive days, during sessions of approximately one and one-half hour duration. In any session each subject was required to make sixteen paired-comparisons between a simulated sonic boom with certain characteristics and a recorded subsonic fanjet flyover noise (a DC-8, during approach to landing and at an altitude of 500 ft). The recorded flyover noise was filtered during playback to provide the "indoor" spectra of the aircraft noise. The aircraft noise was presented to the subjects at four different levels of intensity with 5 dB between levels. Each aircraft noise was paired with sonic booms. Each comparison pair was given twice, once with the boom first in the pair, and once with the aircraft noise first. The subjects were required to rate each pair of sounds with respect to which member of the pair would be more acceptable if heard in or near the home during the day or evening when the subject was engaged in typical, awake activities. Four comparisons between two booms or two flyover noises of identical characteristics were also made to detect a possible stimulus location bias. (None was found.) A copy of the instructions and the form for recording responses is included as Appendix A.

Stimuli. Mechanical limitations of the sonic boom simulator

prevented changing the rise time of the boom signature between trials. Consequently, for any session the characteristics of the sonic boom remained the same, and counterbalancing between the aircraft noise and the boom was used in an attempt to control possible order effects due to the sequence of stimuli presented in the different sessions. The resulting sequence in the various sessions is shown in Table I.

During each session the stimuli were presented in random order with the restrictions that each of the four flyover test intensities be presented four times, and that in half of the trials the boom be presented as the first member of the pair, while in the other half of the trials the flyover was to be presented first. A verbal warning that a pair of stimuli would be occurring preceded the first member of a pair by about 30 secs. After the first member of the pair of stimuli ended, an interval of about 7.5 secs occurred before the second number of the pair was presented. About 2-1/2 minutes elapsed between each pair stimuli. Some pertinent parameters of the stimuli used in this study are shown in Table II.

Table I

TEST SEQUENCES OF VARIATIONS IN SIMULATED SONIC BOOM SIGNATURE
AND RISE TIME COMPARISON NOISE WITH THAT FROM A SUBSONIC JET,
LANDING AT 5000 LBS THRUST

Group Number	Number of Subjects	Selected Boom Characteristics* As Measured Outdoors	
		Test Session 1	Test Session 2
A	3	1.5 psf R.T. = 3.5 ms	2.0 psf R.T. = 9.0 ms
B	4	2.0 psf R.T. = 9.0 ms	1.5 psf R.T. = 3.5 ms
C	4	2.0 psf R.T. = 9.0 ms	1.5 psf R.T. = 3.5 ms
D	3	2.0 psf R.T. = 9.0 ms	1.5 psf R.T. = 3.5 ms
E	3	1.5 psf R.T. = 3.5 ms	2.0 psf R.T. = 9.0 ms
F	3	1.5 psf R.T. = 3.5 ms	2.0 psf R.T. = 9.0 ms

*The sonic booms all had a duration of 290 ms as measured out of doors.

Table II
SELECTED PARAMETERS OF THE STIMULI USED

Stimulus	Intensity as if Measured Out of Doors		Intensity as Measured Near Ear of Subjects	
			Max dBA	EPNdBM **
Full Sonic Boom, 3.5 ms R.T. 290 ms Duration	1.5 psf	100 dBA	79	79
Full Sonic Boom, 9.0 ms R.T. 290 ms Duration	2.0 psf	100 dBA	78	78
DC-8, Landing 5000 lbs Thrust 500 ft Away	118 EPNdBm *	105 dBA	79	88

* To obtain lower values as shown later, attenuation in 5-dB steps was added to circuit after a fixed gain amplifier.

** EPNdBm refers to typical EPNdB modified (M) for critical bandwidth of ear, and impulse (see later discussion).

RESULTS AND DISCUSSION

The results of the judgment tests are given in figure 1. In accordance with the usual procedures for treating paired-comparison data, a perpendicular is dropped to the abscissa from the point at which the curves cross the 50% line of the vertical ordinate. It is assumed that the subsonic aircraft noise at the intensity shown at that point on the abscissa would be judged equal in noisiness to the sonic boom; i.e., 50% of the people would prefer the boom in this regard, and 50% the aircraft noise. The abscissae on figure 1 are representative of a number of physical measures that can be made or calculated for the booms and aircraft noise. The values of the stimuli in a variety of physical units of maximum and effective perceived noise level (Max PNL, and EPNL)

when at the levels required for judged equality were determined in the manner illustrated in figure 1 and are reported in Table III. The procedures for the measurement and calculation of these units are given in refs 6 and 7. In brief, Max PNL is the maximum value for a respective dBA or PNdB unit that is present in any .5-sec segment of time during the occurrence of a boom or aircraft flyover noise; EPNL is the sum, on a power basis, of the PNLs present during each of the .5-sec segments of time between the 10-dB downpoints from the maximum PNL minus 12 dB (the -12 is a constant required from the choice of 8 secs as a reference duration to be used for EPNL). The subscript t1 refers to a tone-correction procedure proposed by Kryter and Pearsons (ref. 8) and t2 to the tone-correction procedure used by the FAA (ref. 9). The "M" refers to a modified form of calculating PNdB wherein the sound pressure levels in the one-third octave bands below 355 Hz are combined in certain ways before calculating PNdB to take into account the "critical bandwidth" of the ear. Finally, the subscript "i" indicates that the PNL for an impulsive sound, in this case the sonic boom, is corrected in accordance with a startle or impulse factor that apparently influences the perceived noisiness of impulsive sounds (ref. 6).

It is perhaps unfortunate that it is necessary to express the levels of the booms and aircraft noise in all these various units. However, a basic goal of the present study was to further test the hypothesis that it is possible to derive a common way of measuring and weighting the spectra and duration of a noise, be it impulsive or nonimpulsive, for the prediction of its perceived noisiness. The units included in Table III are those which for various practical or research reasons are of some interest to those concerned with the measurement and evaluation of noise. In the present experimental procedure, the unit of physical measurement that best predicts the subjective judgment would be the one that has the same numerical value for all noises that are perceived as being equally noisy or unwanted.

Effect of Rise Time. Attention is invited to the fact that the boom having a rise time of 3.5 msec and a peak overpressure of 1.5 psf (as measured outdoors) is judged relative to the aircraft noise to be about as unwanted or noisy as the boom having a rise time of 9.0 msec but a peak overpressure of 2.0 psf. Thus, although the peak overpressure of the boom with a rise time of 9.0 msec is about 3 dB greater (from 1.5 to 2.0 psf) than that of the boom with a 3.5 msec rise time, there is only about 1 "dB" difference in the level of the subsonic aircraft noise judged to be equally noisy; also, the Max and EPNL levels of the booms are, for a given unit of measurement, the same or differ by only 1 dB.

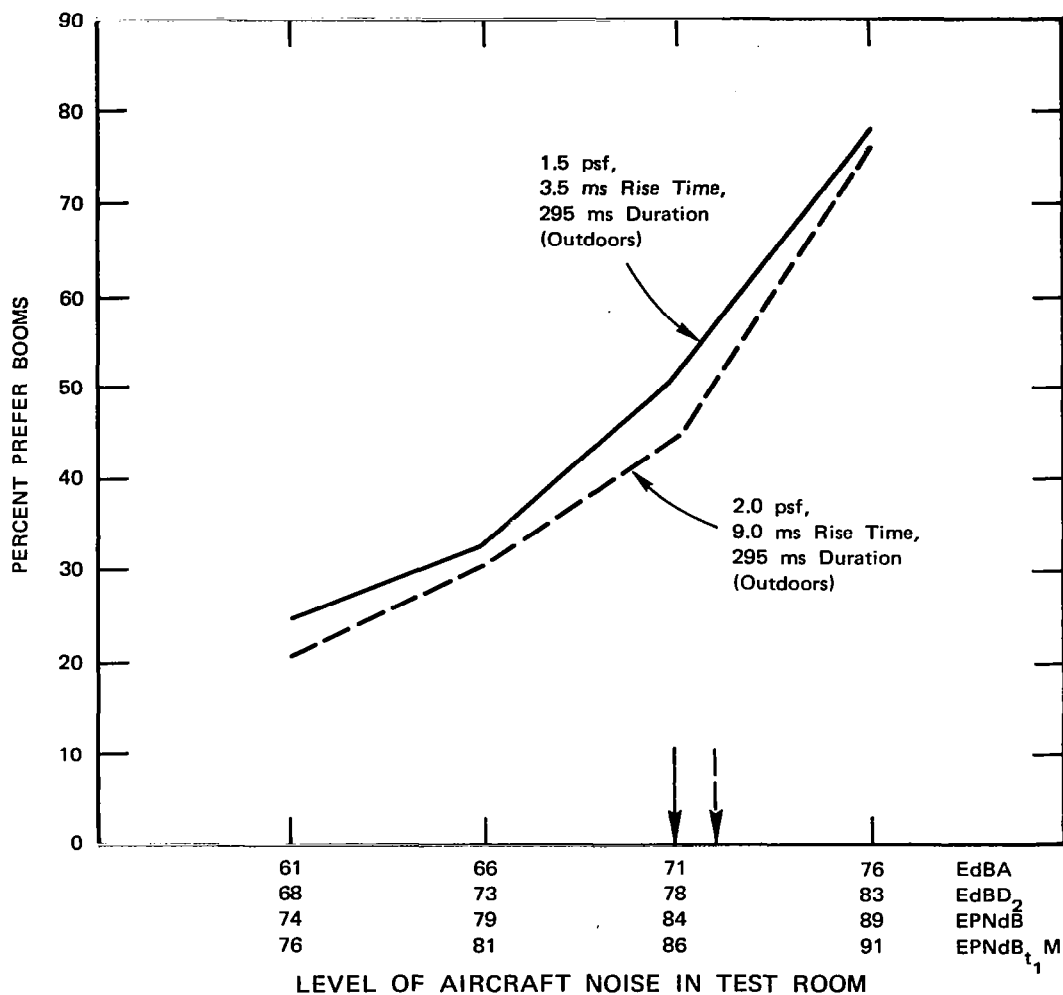


FIGURE 1 SHOWING PERCENT OF PEOPLE WHO PREFERRED THE SONIC BOOMS INDICATED TO AIRCRAFT NOISE PRESENTED AT DIFFERENT LEVELS OF INTENSITY. The arrows mark the noise levels that would result in 50% of the people preferring the boom and 50% preferring the aircraft noise.

Table III

EFFECTIVE AND MAXIMUM PERCEIVED NOISE LEVELS
OF AIRCRAFT NOISE (LEFT-HAND COLUMN)

WHEN JUDGED EQUAL TO THE SONIC BOOMS AS MEASURED IN SIMILAR UNITS
All values are for the sounds in the test room. Also shown are the differences between the physical units for the noise and sonic booms when judged to be equal. The average difference presumably represents the value of the impulse correction, "i".

	A/C	Boom 3.5 ms R.T.	Diff	A/C	Boom 9.0 ms R.T.	Diff	Average Diff (i)
EdBA	71	67	-4	72	66	-6	-5
EdBD ₂	78	77	-1	79	75	-4	-2.5
EPNdB	84	81	-3	85	80	-5	-4
EPNdB _{t₁}	87	81	-6	88	80	-8	-7
EPNdB _{t₂}	86	81	-5	87	80	-7	-6
EPNdBM	83	78	-4	84	78	-6	-5
EPNdB _{t₁} M	86	79	-7	87	78	-9	-8
EPNdB _{t₂} M	85	79	-6	86	78	-8	-7
Max dBA	74	79	+5	76	78	+2	+3.5
Max dBD ₂	82	89	+7	83	87	+4	+5.5
Max PNdB	88	93	+5	89	92	+3	+4
Max PNdB _{t₁}	91	93	+2	92	92	0	+1
Max PNdB _{t₂}	90	93	+3	91	92	+1	+2
Max PNdBM	87	91	+4	88	90	+2	+3
Max PNdB _{t₁} M	90	91	+1	91	90	-1	0
Max PNdB _{t₂} M	89	91	+2	90	90	0	+1

This would be expected to occur because the major part of the spectra of the boom having the most effect upon the ear shifts upward from a center frequency of about 100 Hz to about 300 Hz as the rise time of the boom was shortened from 9.0 msec to 3.5 msec. The greater sensitivity of the ear to the higher frequencies more than compensates for the greater overall sound pressure level of the boom with the longer rise time. This finding is, of course, consistent with the proposals and data of Kryter (ref. 10), Zepler and Harel (ref. 11), and Shepherd and Sutherland (ref. 12) to the effect that the spectrum of a sonic boom can be used as a means of predicting its judged loudness or noisiness.

Impulse Correction. The apparent additional unwantedness or noisiness which is not predicted from effective measures is shown in Table III to be about 7 dB. That is, the indoor boom measured in EPNL units is about 7 dB less than the noise from a subsonic aircraft judged equally noisy. In figure 2 an impulse correction of boom measures in EPNL units is plotted as a function of impulse level above the background noisiness. The relationship shown for the listeners outdoors was obtained from the Edwards sonic boom experiment of ref. 1 and that for the listeners indoors was obtained from the present study. From figure 2 it is seen that the correction for listeners indoors is about one-half the impulse correction for listeners outdoors. This type of impulse correction seems to be an appropriate procedure necessary to take into account the "startle" or "impulse" factor affecting judgments of sonic booms and a means for directly comparing these judgments with those of non-impulsive aircraft noise.

This smaller difference for the indoor noises could perhaps reasonably be attributed to either or both: (1) the rise times of the booms generated by the simulator in comparison with those from actual aircraft, and (2) the "dullness" added to the boom by the room structure. This later hypothesis is, of course, not independent in a strict physical sense from the longer-rise-time hypothesis.

In any event, the notion is intuitive that there is a psychological effect upon the listener from even familiar, expected impulsive sounds that is not reflected in the typical spectral-temporal measurements and should probably not be considered as sufficiently tested for purposes of general use. It should also be understood that the hypothesis that the impulse level-to-background noise level, as shown on the abscissa of figure 2, is an important variable remains to be experimentally demonstrated. As a practical matter, however, it is tentatively suggested that the two impulse correction functions shown on figure 2 be used; one for impulses generated and heard outdoors (or even possibly generated and also heard indoors), and one for impulses generated outdoors but heard indoors.

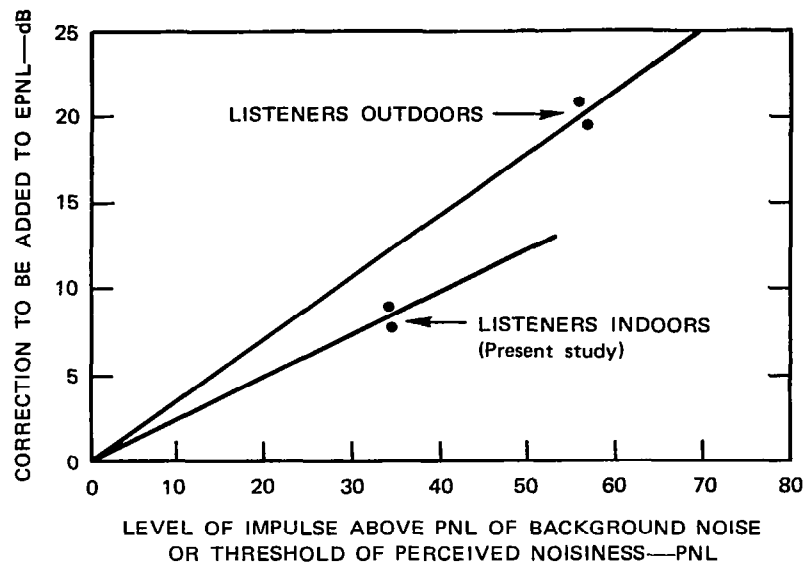


FIGURE 2 CORRECTION TO EPNL FOR CONTRIBUTION TO PERCEIVED NOISINESS OF STARTLE TO EXPECTED IMPULSIVE SOUNDS. The level of the impulse is taken as the amount [in EPNdB_{t_1}] that the impulse exceeds the PNL [in $\text{EPNdB}_{t_1 M}$] of the background noise. The plotted points for listeners outdoors are from judgment tests of the unacceptability of sonic booms versus the noise from subsonic jet aircraft. [Kryter et. al., Reference 1.]

An additional requirement for predicting from physical measures the unwantedness of impulsive and non-impulsive sounds, for that matter, is that the sounds must be familiar to the listeners and an expected part of their environment. These conditions were met in the relevant studies here involved, but the impulse correction obviously cannot be expected to be applicable in tests of the relative noisiness of unfamiliar impulsive sounds with more familiar non-impulsive ones.

Max vs. Effective Values. It is seen in Table III that some of the Max PNL units differ somewhat less between booms and aircraft noise judged to be equally noisy than do their EPNL counterparts. However, this somewhat better agreement could be fortuitous and should probably not be taken to mean that Max PNL is a generally more accurate predictor of judged noisiness. Indeed, tests with non-impulsive aircraft and artificial noises of widely different durations shows that EPNL values are better predictors than Max PNL values of judged noisiness (refs. 13,14). Accordingly, it seems to us that the EPNL unit that best predicts the judged noisiness of the widest variety of non-impulsive sounds is a reasonable prerequisite for choosing a general unit of physical noise measurement. According to this criterion, the unit $EPNdB_{t_1M}$ or $EPNdB_{t_1M_i}$, when impulse-corrected for sonic booms, would be a logical choice on the basis of presently available data. The abscissa on figure 2 was selected on that basis.

CONCLUSIONS

It is concluded that:

1. In order to best predict from physical measures the subjective noisiness of sonic booms when compared with the noise from subsonic aircraft noise, it appears necessary and appropriate to apply an "impulse" correction value to EPNLs measured or calculated for the sonic booms.
2. On the basis of the present study and previous tests conducted with sonic booms and subsonic aircraft noise heard outdoors, a graph of the functions for correcting PNLs of impulses for outdoor and indoor listening can be tentatively proposed. The amount of impulse correction for a given sonic boom when heard indoors appears to be about one-half of that required for listening to the same boom outdoors.
3. Spectral differences due to variations in the rise times

of sonic booms affect the judged noisiness of the booms as heard indoors.

4. The relative effects of the spectral changes on judged noisiness are consistently predicted by the various Max and EPNL units of sound measurement commonly used for evaluating typical subsonic aircraft flyover noises.

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Appendix A

INSTRUCTION TO LISTENERS

LAST NAME												INITIAL
P	DATE		MONTH		LOC.		ISO.					

CIRCLE A IF FIRST SOUND IS MORE ACCEPTABLE. 1. A B
 CIRCLE B IF SECOND SOUND IS MORE ACCEPTABLE.

2. A B

3. A B

4. A B

5. A B

6. A B

7. A B

8. A B

9. A B

10. A B

11. A B

12. A B

13. A B

14. A B

15. A B

16. A B

17. A B

18. A B

19. A B

20. A B

INSTRUCTIONS:

The primary purpose of the tests being conducted is to determine, if possible, how people feel about the *relative* acceptability of one type or level of aircraft noise when compared with a second type or level of aircraft noise.

You will hear a series of sounds from aircraft. Some of the sounds will be sonic booms and some will be the sound made by a subsonic jet aircraft. The sounds will occur in "pairs" and your task is to judge which sound in each pair you think would be more acceptable to you if heard in or near your home during the day and/or evening when you are engaged in typical, awake activities.

After you have heard each pair of sounds please quickly decide which of the two you feel would be more acceptable to you. If you think the second sound of a pair would be more acceptable, circle B for that particular pair. If you think the first sound in the pair would be more acceptable to you than the second, circle A.

Please concentrate on the judgment at hand and give an answer even though the two sounds may seem approximately equal in acceptability to you. If you feel that there is absolutely no real difference in terms of acceptability of the two sounds, please circle either A or B, giving the best guess you can, and put a question mark after that pair.

There are no "right" or "wrong" answers, nor do we expect people to agree with each other. We are interested in how you feel about the sounds and how people differ in their judgments of the acceptability of these aircraft sounds.

An announcement will be made before each pair of sounds is to occur. The sounds of a pair may be separated in time by several minutes; usually, however, they will occur within a single minute. During this period we ask that you be quiet and attentive. Give us your best judgment and imagine, if you will, that you are listening to these sounds in or near your own home.